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## AXIAL LOW-VELOCITY IMPACT RESPONSE OF ANISOTROPIC ANTI- TETRACHIRAL FILLING LATTICES

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### ABSTRACT

Interest to crash response of vehicle parts is increasing closely related with their importance for safety of passengers. In low velocity crash case, integration of foams to tubular systems shows positive effect on the performance. While foams are classified stochastic micro lattice structures, recently, dynamic behaviour of lattices in macro size are being researched with 3D printing technique. In addition to conventional macro lattices showing positive Poisson's ratio have good energy absorbing capabilities, with only geometrical modification macro lattices with negative Poisson's ratio can be created and have better energy absorbing capability than conventional ones. In this study, in different dimensions, blocks of anti-tetrachiral metallic lattices exhibiting negative Poisson's ratio, are modelled. Crushing behaviour of them is investigated under low-velocity impact using explicit and implicit FEA tools. With the results of this study, suitable width-length ratio of macro level anisotropic anti-tetrachiral lattices will be able to classified. In addition to that, force-time behaviour in different impact velocities will be able to understood to use in not only tubular systems but also in sandwich structures as core part.

**Keywords :** crash response, auxetic, finite element, impact

### INTRODUCTION

Crash safety of the vehicles encountered against the impact in different velocities is very important. Crash in automobiles are classified as low-velocity impact. Research on occupant safety is continued while in these velocities (1-20 m/s) the crashboxes in front of the vehicles are designed in strict standards. In this manner, different type of materials are suggested by researchers to have efficient products. Aluminium or steel based crash tubes are still important for crash tubes while new, made of carbon fiber tubes are being manufactured.

The most important phenomenon in a crush or crash situation is surely to absorb the kinetic energy. Crash tubes are designed for that purpose of absorbing crash or crash energy of an impact situation. They have the ability to absorb and convert large amounts of kinetic energy into plastic strain energy under severe loading conditions. Therefore, crash tubes' practical usage area provide a continued interest on their axial crashing and crushing behaviour (Abramowicz and Jones 1986; Alavi Nia and Haddad Hamedani 2010; Jensen et al. 2004; Jones 1996; Karagiozova et al. 2000; Wierzbicki and Abramowicz 1983; Zarei et al. 2008).

Foam filling materials result in a significant improvement when they are used in crash tubes aiming passive safety of the vehicle, owing to their excellent energy dissipation properties. Effort is currently underway to minimize occupant head injury during an impact. The severity of injuries can be prevented or at least mitigated by the use of structural foams as cushioning. Energy is dissipated through the cell bending, buckling or fracture, but the stress is generally limited by the long and flat plateau of the stress-strain curve. This behavior explains the high-energy efficiency that can be obtained with foamed materials. Moreover, for the same amount of dissipated energy, the foam specimen always gives a maximum force lower than the corresponding solid specimen of equal volume made of the material from which the foam is derived. Toksoy and Güden investigated effect of aluminium and poly-styrene foam fillings in cylindrical tubes (Aktay et al. 2006; Toksoy and Güden 2005). As a result of foams' interaction with tubes, buckling type and efficiencies of tubes are changed. Mohammadiha and Beheshti (2014) studied effect of functional graded foam density in conical tube. Abedi et al. (2012) developed theoretical models for empty and foam filled quadrangle columns to compare experimental and FEA results.

Lattice structures are widely used in aerospace, automobile, space applications for their superior impact absorbing and vibration damping capabilities. They can be constructed in micro (Liu et al. 2014; Smith et al. 2013; Vaziri and Ghosh 2014) or macro level (Lee et al. 2013; Liu et al. 2015; Smith et al. 2013). In term of micro level, foam structures are classified as lattice structures too. Foams are tested in crash tube applications as an example of stochastic micro lattices while macro level lattice structures are used in sandwich structures as core material. Measuring crush force efficiency of macro lattice in passive safety components is needed to investigate as their sandwich core applications. In addition to foams' showing conventionally positive Poisson's ratio, recently, there is increasing interest to the auxetic materials which are showing negative Poisson's ratio thanks to its higher energy absorbing capability for impact response (Scarpa et al. 2004; Schultz et al. 2012; Zhang et al. 2015). Zhang et al. (2015) studied crushing behaviour of a type of auxetic lattices as a honeycomb with finite element analysis and according different impact velocities, plate stress and stress- strain diagrams are created.

In this research study, auxetic anti-tetrachiral lattice structures are modelled to analyse with aim of measuring energy absorbing capability. Due to nature of crash event, metallic lattice absorbing more energy comparing to plastic lattices are modelled in ABAQUS software. Low velocity impact behaviour of anisotropic anti-tetrachiral lattices are measured by scaling lattice parameters for filling crash tubes. Superior mechanical performance of this lattices has been reported previously (Chen et al. 2013). Current study will address dynamical response of anti-tetrachiral lattices. In addition to that, lattice blocks being investigated in this study will be able to be placed as multi-storied sandwich structure in crashboxes so that new crash box designs can be created.

## NUMERICAL SIMULATION

Vehicle passive safety components are designed according their crush force efficiency and specific energy absorption values. For this purpose, peak crush force, mean crush force and deflection data under axial impact load are obtained. In this step, as a filling material, designed anti-tetrachiral systems's crush force response is investigated autonomously. In addition to crash tube or sandwich systems's efficiency measurement with these data in low velocity impact, as a foam behaviour measurement tool; force-time curve is created to measure efficiency of macro or micro level anti-tetrachiral lattices. Plateau and densification behavior of lattices are observed in post-process section of the analyses.

Due to a few experimental and numerical investigation on crushing of lattice geometries, the numerical model is constructed with material data that has been verified with crash tube collapse tests (Fig. 1) (Chanh Nghia et al. 2014). Three different designs are modelled with x1 scale, x0.5 scale and x0.25 scale of unit lattice cells, respectively. “x1 scale” of lattice is represented in the Fig. 2.

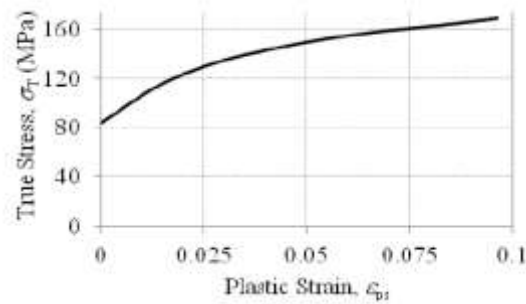


Fig. 1 Aluminium 6063 T1 true stress-plastic strain diagram that is input for CAE programs (Chanh Nghia et al. 2014)

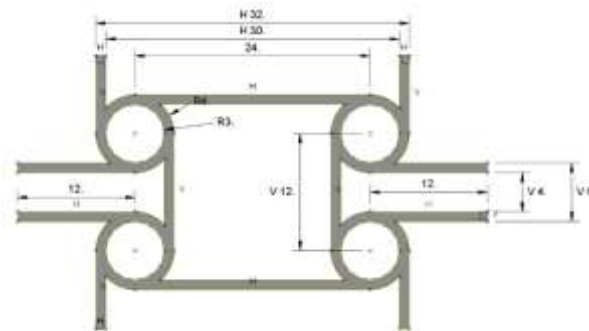


Fig. 2 Lattice geometry of scale x1 (=L)

Numerical analyses are conducted using 0.5 and 0.25L lattices due to “L lattice”s having too low relative density. The applied impact load can cause easily deformation for selected small piece of volume. That is not intended for this study. The Table 1 summarizes the constructed models in ABAQUS/Explicit environment. There are small number of lattices in each direction for each design because that these lattice will be constructed with gaps in possible sandwich structures. In this manner, global buckling of blocks is not desired for efficient plastic collapse. To decrease the possibility of global buckling, smaller unit lattices are modeled to observe their force-time curves.

Table 1 Design Consideration

Design no:		Number of lattice in width	Number of lattice in height	Number of columns	Mass of systems (g)
1	0.5L	2	4	2	18.30
2	0.5L	4	4	2	36.50
3	0.25L	4	8	4	18.20
4	0.25L	4	10	4	22.75

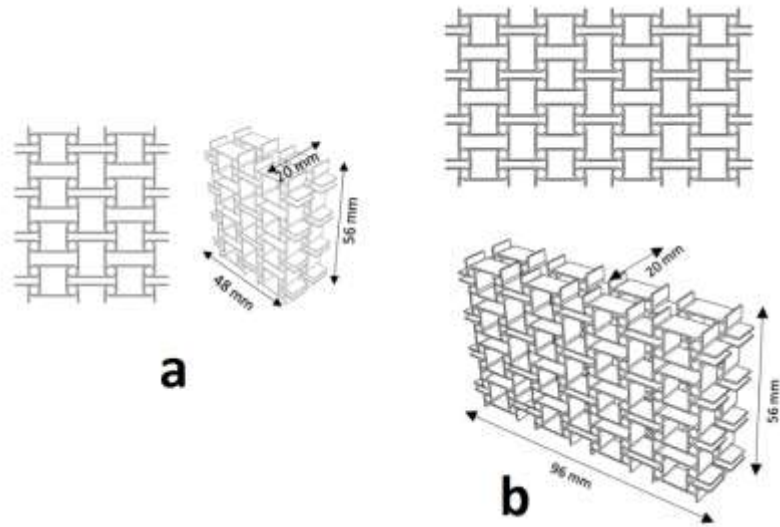


Fig. 3 Lattice structures with 0.5 L unit cell a) Design 1 b) Design 2

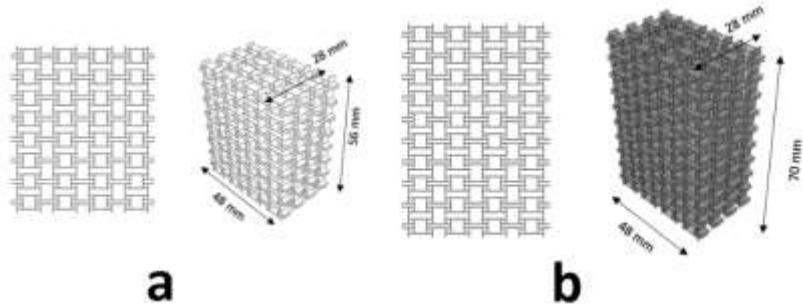


Fig. 4 Lattice structures with 0.25 L unit cells a) Design 3 b) Design 4

Solid elements (C3D8R) are used to model anti-tetrachiral lattices in ABAQUS software. Rigid base and top plates are modelled to crush the lattices under dynamic impact loading. The contact interaction is created between plates and lattices along with self interaction of lattices. For 0.5L unit lattice systems, global buckling phase occurs after auxetic behavior. The Fig. 5 represents explained crushing with their timings. Until 0.017 seconds, negative Poisson's ratio is protected, later collapse including global buckling is continued. In the Fig. 6, auxetic behavior with local plastic collapses are observed, however, after the 0.0018 seconds global buckling starts with continuing local plastic collapses.

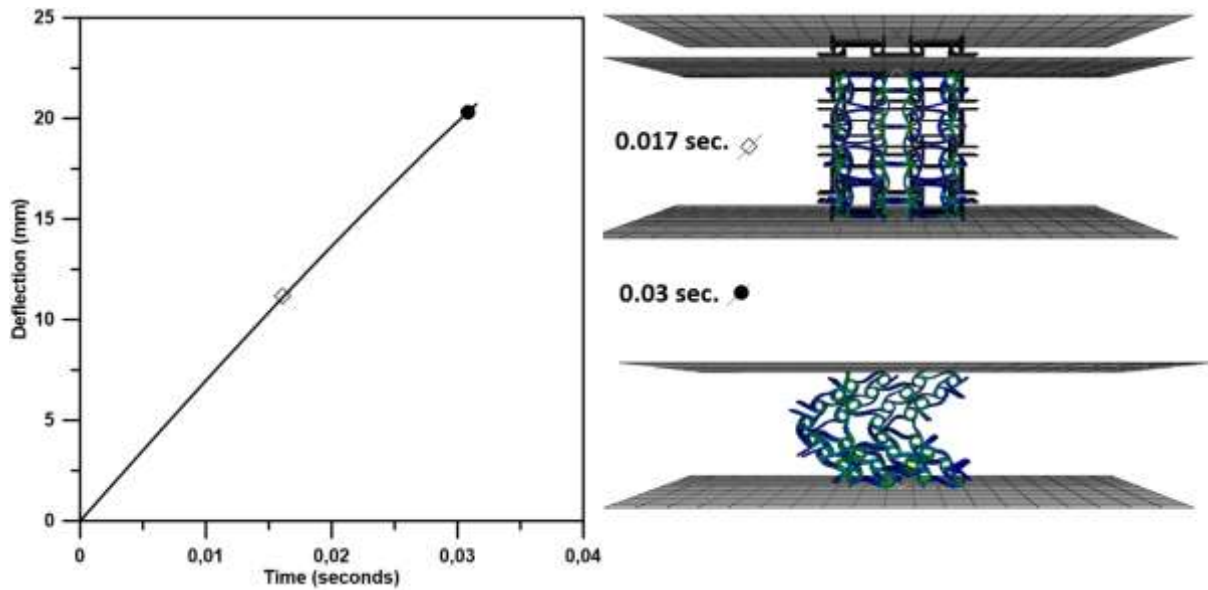


Fig. 5 Last stand at 0.017 sec. as auxetic behaviour and global buckling and failure of lattice block at 0.030 sec. of 0.5L auxetic block (Design 1)

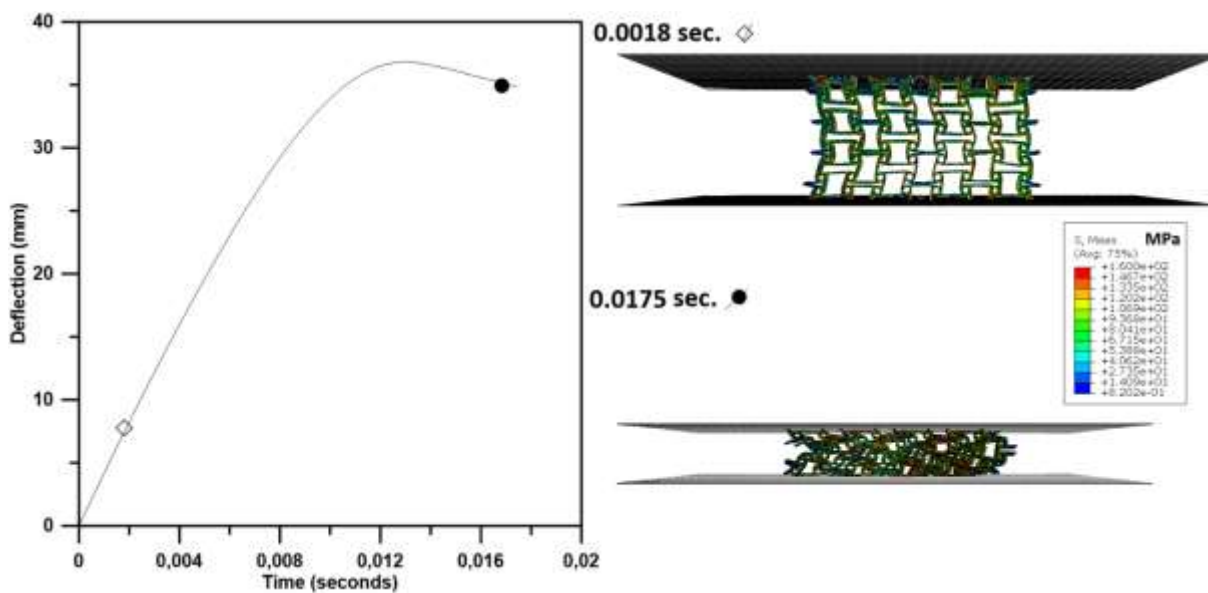


Fig. 6 Last stand at 0.0018 sec. as auxetic behaviour and global buckling and failure of lattice block at 0.0175 sec. of 0.5L auxetic block (Design 2)

Force-time behaviour comparison between auxetic lattice system having 8 lattices in height, 4 lattices in width, 4 columns with 0.25L unit lattice parameters and differently system having 10 lattices in height is compared in the Fig. 6. Again, for both systems velocity-time plot is given in the Fig. 7. Selected two designs with 0.25L and 0.5L lattices, respectively are compared in the Fig. 8. In same figure, global buckling time and auxetic threshold are showed to understand auxetic behavior. Local bucklings in the Design 3 and 4 that are constructed with 0.25L lattices are aimed results to have higher energy absorption. Force-time behaviour of different designs having different unit lattice dimensions give an idea about energy absorption capacities of them.

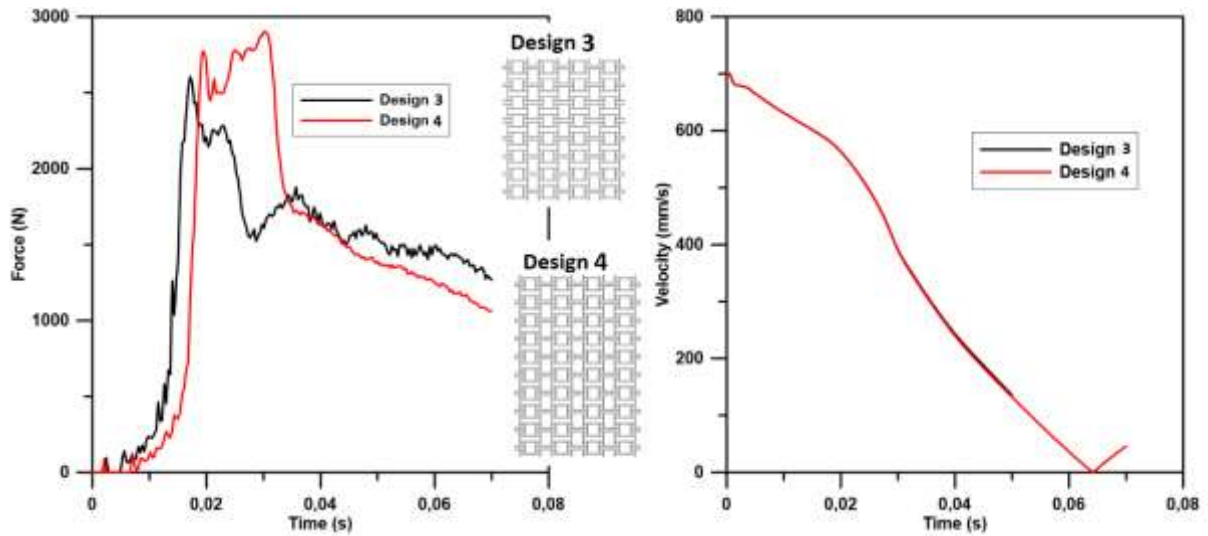


Fig. 7 Reaction force and velocity curves of two type of 0.25L auxetic block at 700 mm/s velocity

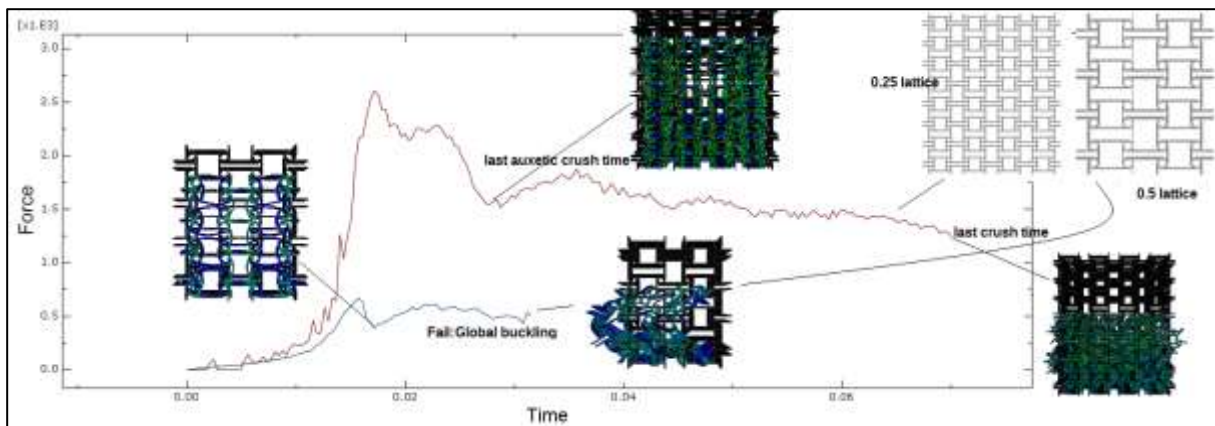


Fig. 8 Force-time behaviour comparison of 0.25L (Design 3) and 0.5L (Design 1) including thresholds of auxetic behaviour and global bucklings

3rd design is crushed with different impact velocities (700 mm/s, 1000 mm/s, 1300 mm/s) and velocity-time behaviour of these are shown in the Fig. 9. As expected, velocities goes to zero according the initial values. Under 1300 mm/s auxetic lattices shows the highest densification stress as in the Fig. 9.



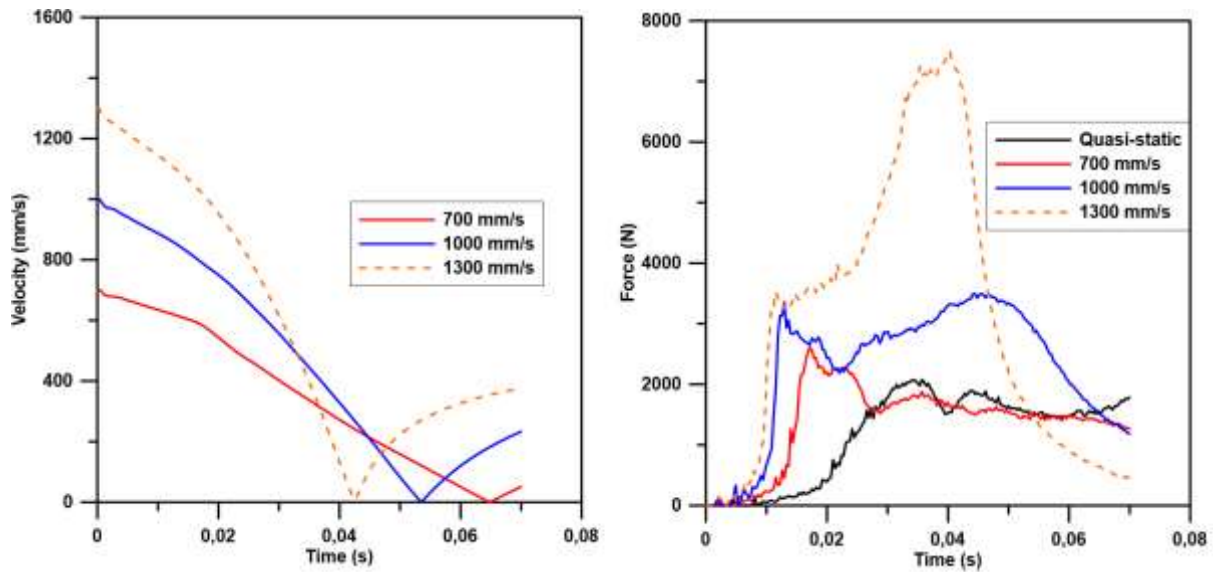


Fig. 9 Velocity-time and force-time plots of different crash velocity scenarios of 0.25L w:4 h:8 lattices (3rd design)

## CONCLUSION

Anti-tetrachiral auxetic lattices made of aluminum has been numerically investigated under dynamic loading condition. Dynamic loading is arranged according dimension of small lattice samples. Analysis samples are augmented by increasing number of lattices in two directions. In this aspect, global buckling has been observed in the Design 1 having lower relative density comparing other ones. The force-time curves of designs are obtained to understand energy absorption levels. According these results, structures having higher relative density has exhibited higher reaction force and so higher energy absorption. The design 3 has been selected as a unit stack when higher height is not effective on the decreasing of impact velocity in such small dimensions. As a pre-investigation, this study shows plastic collapse response of anti-tetrachiral lattices in different orders and scales. After the designs are placed as a sandwich core by interspacing, laminated sandwiches are placed in a crash box to enhance energy absorption. 0.25L lattice designs have higher energy absorption capability than 0.5L ones due to their higher relative density.

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